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Rediscovery of the 'extinct' Lord Howe Island stick-insect (*Dryococelus australis* (Montrouzier)) (Phasmatodea) and recommendations for its conservation

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Abstract. The Lord Howe Island Stick-insect (*Dryococelus australis*) was formerly abundant on Lord Howe Island, Australia, but was extirpated by Black Rats (*Rattus rattus*) in the 1920s. The species was thought to be extinct, until freshly dead remains were found by climbers on Balls Pyramid during the 1960s. In February 2001, a survey of Balls Pyramid led to the discovery of a small population of *D. australis* on a precipitous terrace 65 m above sea level. Two adults and one nymph (all females) were located feeding on an endemic tea-tree (*Melaleuca howeana*). An accumulation of plant debris at the base of the shrub, kept moist by water seepage, provided the insects with damp hollows suitable for use as daytime refugia. All evidence indicated that the species was confined to this single small terrace. A second survey, in March 2002, located a total of 24 *D. australis*. Twelve individuals were in the same shrub as that occupied the previous year, and 12 were dispersed among five nearby, smaller shrubs. Ten individuals were able to be sexed – eight females and two males. A number of threats to the population of *D. australis* on Balls Pyramid are identified and several management actions are proposed to ensure the conservation of the species.

Introduction

Worldwide, there are about 0.75–1 million known species of insect (class Insecta) (IUCN 1983), of which 72 species are currently regarded as recently extinct (IUCN 2000). Butterflies and moths (order Lepidoptera, 38 species) and beetles (Coleoptera, 17 species) feature prominently among the extinctions, which also include flies (Diptera), caddis-flies (Trichoptera), mayflies (Ephemeroptera), mealy bugs (Homoptera) and a single species each of dragonfly and damselfly (Odonata), grasshopper and katydid (Orthoptera), stonefly (Plecoptera) and stick-insect (Phasmatodea) (IUCN 2000).

The majority of these extinct insects came from island communities, particularly those that exhibited a high degree of endemism. The Hawaiian Archipelago is possibly the worst affected, due largely to the widespread conversion of lowland and montane forest into pineapple and sugarcane plantations (Opler 1976). At least 40 known species of insect have been lost from these islands (IUCN 2000), and many more species are likely to have become extinct before they were known to science (Opler 1976). Globally, the principal causes of insect extinctions include deforestation, changes to aquatic environments, atmospheric pollution, loss of hosts, the introduction of exotic plants and animals, over-collecting and the use of pesticides (IUCN 1983).

The largest of the extinct insects is the Lord Howe Island Stick-insect (*Dryococelus australis* (Montrouzier)). This species was endemic to Lord Howe Island (31°33′ S, 159°05′ E), a small (14.55 km^2) volcanic island situated in the Tasman Sea, 770 km northeast of Sydney, Australia (Figure 1). Known locally as the 'Land-lobster' or 'Tree-lobster', this large, flightless insect was formerly abundant (Etheridge 1889) but was extirpated by Black Rats (*Rattus rattus*) in the early part of last century. Live specimens of the insect have not been seen since the 1920s (Paramonov 1963) and nothing is known about its ecology other than a brief account of its habits given by Lea (1916). Lea described *D. australis* as nocturnal, emerging at night to feed on leaves in the canopy. Regrettably, there is no record of any host food plant. By day, the insects secreted themselves inside hollows formed in the trunks of living trees, particularly those made by larvae of the Large Longicorn Beetle (*Agrianome spinicollis*). As many as 68 individuals were found inside a single hollow. Particular hollows appeared to be occupied for many years, as evidenced by the large heaps of frass (excrement), sometimes amounting to 'several bushels' (Lea 1916), that collected at the foot of some trees.

Both eggs and eggshells were present among the frass indicating that, like most other stick-insects, *D. australis* release their eggs while suspended above ground (Lea 1916).

D. australis was first described by Montrouzier (1855) from specimens collected a few years earlier by officers of the surveying vessel HMS *Herald* (Holland 2001). The species was subsequently also described by Westwood (1859). Adults are large (female body length 120 mm, male 106 mm), heavy bodied and wingless. Preserved specimens have a smooth, shiny exoskeleton that is dark red–brown in colour with a blackish tinge on the head and thorax. Sexes are readily distinguishable: males having longer and thicker antennae, greatly enlarged and spined hind femora, and a narrower abdomen which lacks the ovipositor of the female (Lea 1916; Gurney 1947). Eggs of *D. australis*, although present in museum collections, have not been described.

On Lord Howe Island, two rugged mountains, Mount Gower (875 m) and Mount Lidgbird (777 m), dominate the landscape. These mountains, together with much of the lowlands, are forested. Forest types include evergreen rainforest, palm forest, *Pandanus* forest and mossy forest at higher altitudes (Pickard 1983). A number of smaller islets occur around Lord Howe Island, the most spectacular of which is Balls Pyramid, an eroded volcanic spire 23 km to the southeast (Figure 1).

On 14 June 1918, the trading vessel 'Makambo' struck a submerged rock off Lord

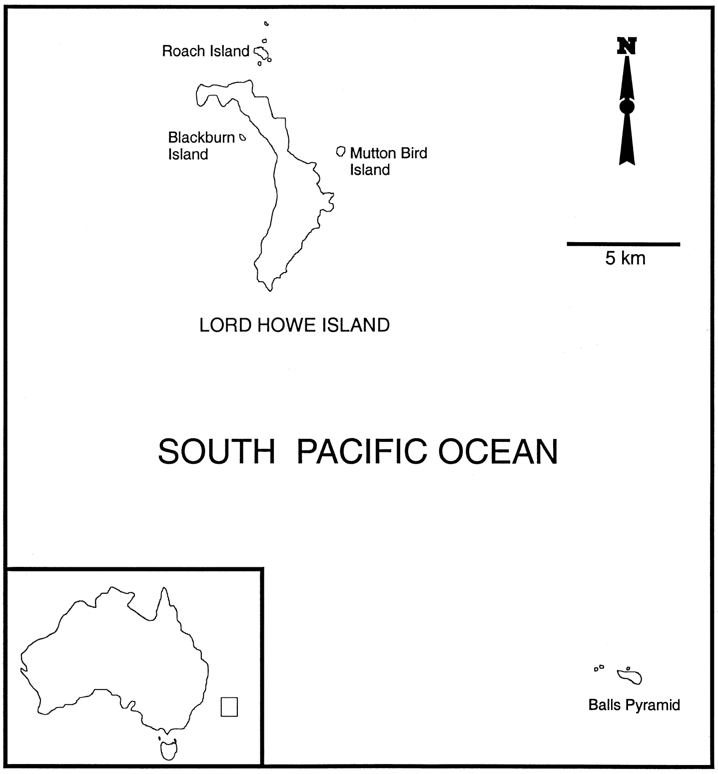

Figure 1. Location of Lord Howe Island and surrounding islets, including Balls Pyramid.

Howe Island, damaging its hull (Wilkinson and Willson 1981 in Hutton 1991). It is believed that rats came ashore with the cargo (Hindwood 1938), and within a few years had spread throughout the island (Edgecombe 1987). As rat numbers increased, *D. australis* rapidly disappeared. By 1935, the species was considered to be very rare, if not already extinct (Gurney 1947). All subsequent surveys of Lord Howe Island have failed to find any trace of the species (Paramonov 1963).

In 1964, a rock climber, David Roots, found and photographed a recently dead adult female at Gannet Green on Balls Pyramid (McAlpine 1966; D. Roots, personal communication). Five years later (1969), the incomplete remains of another two individuals (one adult and one nymph, both female) were also recovered from Balls Pyramid. These remains were found close to the summit (490 m above sea level), one in a small 'woody bush', the other incorporated into a bird's nest (Smithers 1970).

Balls Pyramid is a rocky pinnacle that rises abruptly to 551 m from a base that measures only 1100 × 400 m at sea level. It is composed of volcanic basalt and is largely devoid of woody vegetation. The supposed existence on the Pyramid of a population of large, arboreal insects known only to inhabit holes in the trunks of living trees appears somewhat incongruous. Numerous attempts have been made to locate live *D. australis* on the Pyramid since the first discovery of their remains, but all have been unsuccessful (IUCN 1983; Hutton 1998).

The authors undertook an expedition to Balls Pyramid on 5–6 February 2001 to conduct a biological survey. A prime objective of this survey was to determine whether a population of *D. australis* existed there. If a population was found we aimed to assess, as far as practicable, (i) the size of the population; (ii) the extent of its distribution; (iii) the potential threats to its continued survival; and (iv) its likely vulnerability to disturbance. A second, follow-up survey was conducted on 26–27 March 2002.

Methods

Techniques used to locate *D. australis* included daytime searches for frass, eggs and potential refugia, and nocturnal searches for live animals. All habitats were searched, but greater emphasis was afforded sites that were likely to contain crevices and hollows of sufficient dimension to harbour an insect the size of *D. australis*. Soil below selected shrubs was collected, sieved and examined for the presence of insect frass or eggs.

The area searched was limited to that which was accessible without the use of ropes or specialised climbing equipment. This was an area on the southeastern end of Balls Pyramid that comprised a series of terraces, extending from sea level to Gannet Green, approximately 120 m above sea level. Although the area searched was small in relation to the entire surface of the Pyramid, it encompassed most of the vegetated parts of the island and included those habitats most likely to support a population of *D. australis*. The steeper rock faces above Gannet Green held very little soil and were largely devoid of vegetation. Although dead specimens of *D. australis* had been recovered from near the summit of Balls Pyramid, it is believed that these were carried there by nesting seabirds (see below). Stereoscopic analysis of recent aerial photographs was used to identify potential habitat beyond the area surveyed.

The survey was undertaken in a manner that involved minimal disturbance to the fragile environment on Balls Pyramid. It was also predetermined that if an extant population of *D. australis* was discovered, live specimens or eggs would not be collected, and nothing would be done to jeopardise the immediate or future survival of the species.

Results

First survey (February 2001)

A complete list of floral species found on Balls Pyramid is to be published elsewhere. No trees were present, consequently tree hollows – the daytime refuges of *D. australis* on Lord Howe Island – were entirely absent. An endemic tea-tree

(*Melaleuca howeana*) was the only shrub species present, with approximately 30 individual plants growing within the area surveyed. Although the ground below each of these shrubs was searched for the presence of frass and eggs, only one shrub yielded anything of significance. Below this particular shrub we found a substantial amount of frass, much of it still moist and green. The size of the frass indicated that the insect responsible for it was particularly large.

Two members of the survey team (N.C. and D.H.) ascended the Pyramid at night to conduct a nocturnal search of the area surrounding the shrub where the frass had been found. Reaching this site at approximately 22.00 h, they found, observed and photographed two adult female *D. australis* on the outer edges of the shrub (Figure 2). These specimens, the first to be seen alive in more than 70 years, were highly conspicuous, their glossy bodies strongly reflecting the torchlight. The insects appeared dark golden-brown in colour. A cream stripe extended along the mid-lateral line of the abdomen, the thickness of which tapered posteriorly. No attempt was made to handle the animals or to take morphometric measurements.

When first discovered, one individual was about 15 cm above ground, the other was about 2 m above ground. Both individuals were at the outer margins of the shrub grazing on the red leaf tips of new growth. This is the first recording of a host food plant for *D. australis*. The lower of the two insects was dusty, suggesting that it had traversed along the ground before ascending the plant to feed. Feeding bouts were punctuated by long periods of inactivity. While grazing, the insects were slow moving, but when disturbed, they moved rapidly, quickly ascending higher up the shrub.

Close examination of the inner branches of the shrub revealed a third individual, a

Figure 2. Photograph of a female Lord Howe Island Stick-insect (*Dryococelus australis*) on a *Melaleuca howeana* shrub.

female nymph approximately 8 cm long and identical to the adults except that it lacked the lateral stripe. Once disturbed, this animal rapidly retreated.

Most other shrubs in the survey area were also searched that night, but no more stick-insects were found. The only shrubs not checked at night were eight plants located 15 m above the shrub containing *D. australis*, as gaining access to this area was particularly difficult in the dark. These shrubs had been inspected for the presence of frass during the day, and none had been found.

The shrub occupied by *D. australis* was situated below a sheer rock face on a steeply sloping terrace (~50° incline) about 65 m above sea level, directly below Gannet Green. The shrub measured approximately 3 m wide by 4 m high and was the largest shrub on the terrace. Growing somewhat parallel to the slope, the canopy of the shrub extended both above and below the base of the trunk. Two pairs of seabirds – Common Noddy (*Anous stolidus*) – were nesting on the shrub, their nests marginally reducing the foraging area available to the stick-insects, but otherwise their impact appeared minimal.

The base of the shrub was situated at an interface between several different basaltic lava flows. Moisture seeping through a seam in the rock face just above the base of the shrub had promoted the establishment and growth of other plants within the immediate vicinity. These plants included a grass (*Sporobolus virginicus*), a sedge (*Cyperus lucidus*) and two herbs (*Achyranthes aspera* and *Tetragonia tetragonioides*). Debris from these plants together with litter from the *Melaleuca howeana* shrub had accumulated between the base of the shrub and the rock face behind. This dead plant material, kept moist by water seeping from above, contained numerous hollows and cavities in which the stick-insects could shelter during the day. Some of the larger cavities were the disused burrows of nesting seabirds.

A small quantity of soil and litter (approximately 10 samples each of 800 cc in volume) from below the shrub was sieved and examined. Two *D. australis* eggs (~6 $\times$ 4.5 mm) were found, examined, photographed and replaced. The eggs were beige in colour with a raised, reticulate pattern. The micropylar plate was teardrop shaped and the capitulum of the operculum was circular with a rim facing anteriorly. Unlike the soil at the base of the shrub, which was moist and firm, soil down-slope from its base was dry, friable and unconsolidated. In the interest of minimising disturbance, a comprehensive search to estimate the number and density of eggs under the shrub was abandoned.

Several *Melaleuca howeana* shrubs on the terrace occupied by *D. australis* were being invaded and smothered by the invasive vine Morning Glory (*Ipomoea cairica*). This vine can be particularly aggressive and is thought to have colonised Balls Pyramid only recently. It had penetrated several shrubs near the one occupied by the stick-insects, and if it spread further it could potentially damage the insect's host plants, thereby threatening its continued survival.

Aerial photography revealed that very few shrubs existed beyond the area searched. A small cluster of shrubs on the northern face was inaccessible to us and so was not searched. If this area also contained a seep, it too may have contained habitat suitable for *D. australis*. Examined with the aid of binoculars, however, it seemed that most of the shrubs in this area were situated on near-vertical cliffs or overhangs where soil was unlikely to accumulate. If females were to feed on these shrubs, the eggs they expelled would fall where conditions were not particularly conducive for incubation.

Second survey (March 2002)

The terrace where *D. australis* was found in February 2001 was surveyed again on the night of 26 March 2002. The survey, conducted between 21.30 and 23.30 h, located a total of 24 live *D. australis*. All individuals were located on the outer foliage of *Melaleuca howeana* shrubs where they were apparently grazing on the new leaf tips. Twelve individuals were found on the same shrub where the three individuals were discovered the previous year. The other 12 individuals were dispersed among five nearby, smaller shrubs. All six shrubs occupied by *D. australis* were within an area of about 30 × 6 m, and several contained the nests of Common Noddies.

The extremely unstable nature of the scree made it hazardous to approach some of the stick-insects too closely. Of those that were approached, several hastily retreated. Consequently, not all individuals could be viewed close-up, and of the 24 *D. australis* seen, only 10 were able to be sexed – eight females and two males. These were the first males of this species to be recorded on Balls Pyramid. Stick-insect eggs were seen on the soil surface underneath the principal shrub, but no estimation of their numbers was attempted. Also found and collected was the exuviae (the body covering cast-off during moulting) of a juvenile *D. australis*. On later examination this was discovered to contain a single egg which, presumably, had fallen into the exuviae after being dropped by a female above.

Discussion

Population size and distribution

On Lord Howe Island, *D. australis* formerly inhabited forested areas where it occupied hollows in the trunks of living trees (Lea 1916). Such habitat does not exist on Balls Pyramid and the stick-insects here appear to use cavities formed in accumulated plant debris kept moist by water seeping from the rock face above. The combination of a large shrub, damp conditions and lush plant growth is extremely unusual on the Pyramid. Generally, bare rock predominates, and where soil is present it is usually dry and friable.

The small, extant population located during these surveys was restricted to a single small terrace where the only potential daytime refuge was a single accumulation of moist vegetation that was just a few square metres in area. Small quantities of aged insect frass were found under some shrubs on higher terraces during the first survey. However, no *D. australis* were seen here during either survey, and no suitable daytime refuges were identified. It is likely that this frass originated from another species, such as the large cricket *Austrasolomona personafrons*, one of which was collected in February 2001.

The size of the *D. australis* population on Balls Pyramid is not known, but given the limited extent of potential habitat it is probably very small. In all likelihood, *D. australis* is the world's rarest invertebrate. Only three individuals were seen in 2001 and 24 individuals in 2002. Rainfall in the 12 months preceding the 2001 survey (892 mm) was 58% of the mean annual rainfall (1546 mm), whereas rainfall in the 12-month period preceding the second survey (1729 mm) was 112% of the mean annual rainfall (Australian Commonwealth Bureau of Meteorology database). The amount of water seeping from seams in the basalt face above the terrace occupied by *D. australis* was noticeably greater during the second survey.

Vegetation was also conspicuously more lush than it was the previous year, and the *Melaleuca howeana* bushes held much more new growth. Data are limited, but these findings suggest that population size may vary considerably between years, and that rainfall may be one of the major determinants.

Taxonomic status

Numerous specimens of *D. australis* were collected from Lord Howe Island in the early 1900s and are now held in museums in Australia and elsewhere. As far as could be ascertained from observations, the stick-insects on Balls Pyramid were morphologically identical to museum specimens of *D. australis*. Due to the extreme rarity of this species in the wild, no specimens were taken from the Pyramid for taxonomic study. However, dead specimens collected from Balls Pyramid in the 1960s have been identified as *D. australis* (Smithers 1970). These specimens are currently held in the Australian Museum, Sydney.

Not surprisingly, the live animals differ from preserved specimens in the richness of their colour – a dark, golden brown. Live specimens also had a conspicuous cream lateral stripe along the abdomen. No mention is made of this stripe in the original description of the species or in any subsequent account. The stripe is absent from the majority of museum specimens, but is discernible in some that have been particularly well preserved.

The fine structure of stick-insect eggs differs between species and is particularly valuable for establishing phylogenetic affinities (Mazzini and Scali 1980). The egg taken from the exuviae collected during the second survey was compared with eggs extracted from the ovipositor of museum specimens (Lord Howe Island origin) and with an egg extracted from the dead specimen of *D. australis* collected from Balls Pyramid in 1969. All three eggs were morphologically identical (D.C.F. Rentz, personal communication).

Sex ratio

The three dead specimens found on the Pyramid during the 1960s were all female (McAlpine 1966; Smithers 1970). The three live individuals seen in 2001 were also females, leading to speculation that the species may survive only as an all-female population, reproducing by parthenogenesis – a process common among the Phasmatodea by which unfertilised eggs hatch into females. The discovery of two males in March 2002, however, refuted this proposition. In 2002, the ratio of males to females was 1:4. Overall, the ratio is 1:7. Historical accounts of *D. australis* indicate that males, although not uncommon, were far less numerous than females (Etheridge 1889), and a preponderance of females is not unusual among the Phasmatodea (Key 1991).

Explanation of previous finds

The restricted distribution of live *D. australis* on Balls Pyramid can be explained by the restricted nature of the habitat available. The wider distribution of locations from where dead specimens were recovered previously, however, is more problematic. There appear to be no plants at higher altitudes on the Pyramid capable of providing adequate food or shelter for an insect as large as *D. australis*. One possibility is that the stick-insects found here in the 1960s did not inhabit these locations when alive, but were transported there after death by nesting seabirds. Common Noddies, abundant on Balls Pyramid, frequently incorporate sticks and seaweed into their nests (Higgins and Davies 1996). Sticks are not particularly common on the Pyramid and dead stick-insects are presumably no less attractive than actual sticks. One of the two *D. australis* found by climbers near the top of the Pyramid in 1969 was reported as having been incorporated into a bird's nest (Smithers 1970).

Origin of the population on Balls Pyramid

Lord Howe Island and Balls Pyramid sit on the same large seamount – the Lord Howe Island Rise. Although the expanse of ocean separating the islands was much less during an earlier geological time, the existence of a deep submarine trench (10 km wide and more than 640 m deep) between them suggests they were never actually linked above water (Standard 1967). With no land bridge between the two islands it is interesting to speculate as to how a large, flightless stick-insect might disperse between them.

Eggs or adults may simply have floated to Balls Pyramid from Lord Howe Island, been discarded by fishermen using the insects as bait, or carried there as nesting material by birds. If birds are translocating dead stick-insects around the Pyramid because nesting material is in short supply, they may well have obtained material from Lord Howe Island. If a dead female was brought to the Pyramid as nesting material it is quite plausible that it contained eggs that were still viable. The subsequent survival and hatching of these eggs may have provided the founders of the current population on Balls Pyramid.

Analysis of genetic variability among individuals on Balls Pyramid is likely to yield some useful insights into the origin of the population on the Pyramid. This information would also be important for conservation managers to preserve not only the species, but also its remaining genetic diversity. Comparison with museum specimens from Lord Howe Island may also provide some indication of the period of time that the population on Balls Pyramid has been separated from the population on Lord Howe. Thus, molecular studies involving either DNA analysis or protein electrophoresis, and utilising dead animals or spent egg cases, are strongly encouraged.

Threats and solutions

Although the population of *D. australis* on Balls Pyramid may have existed for at least 70 years, and probably much longer, its continued survival is far from secure. The population is exceptionally small, has an extremely restricted distribution and occupies habitat that appears to be suboptimal. Consequently, the species faces a very high risk of extinction through random stochastic events. Now that the existence and exact location of the population are known, the species is also a potential target for illegal poaching by unscrupulous insect collectors. A number of management actions are proposed to ensure that the species is not lost altogether.

The habitat occupied by *D. australis* is extremely fragile and unstable, consequently any disturbance (including *in situ* scientific research) may have catastrophic consequences for the species. Accordingly, we recommend that access to Balls Pyramid be restricted, at least until a viable colony of *D. australis* is established elsewhere in the wild. Balls Pyramid was formerly popular with rock climbers, but in 1982 it was incorporated into the Lord Howe Permanent Park Preserve and recreational climbing was prohibited because of potential disturbance to seabird colonies (Hutton 1998). Today, access to the Pyramid is allowed only for scientific purposes (Mandis Roberts Consultants 1999) and is tightly controlled by the Lord Howe Island Board.

The invasive vine *Ipomoea cairica* threatens to encroach upon and smother several *Melaleuca howeana* plants – currently the only known food plant of *D. australis* on the Pyramid. To alleviate this threat, we recommend that urgent action be taken to remove all *Ipomoea cairica* plants that potentially threaten the known habitat of *D. australis*. (This action has since been undertaken by the Lord Howe Island Board and was completed without disturbance to *D. australis*, their habitat or the plants on which they feed.) Widespread control of *I. cairica* on Balls Pyramid is not recommended, as this plant helps to consolidate loose soil on many of the steep terraces.

We strongly recommend that consideration be given to establishing a breeding population of *D. australis* in captivity. The establishment of a captive colony will avert the immediate threat of extinction and secure the short-term survival of the species. In the longer term, the captive population could provide the stock necessary to reintroduce the species back onto Lord Howe Island should rats be eradicated. In light of the instability of the soil in the area inhabited by *D. australis*, we suggest that disturbance be minimised by collecting adults rather than eggs.

Remarkable progress has been made in eradicating rodents and other alien predators from islands (Veitch and Bell 1990). In New Zealand alone, more than 90 islands have been successfully cleared of introduced mammals (Towns et al. 2001). Many of these eradications involved the removal of one or more species of rodents, including Black Rats, Pacific Rats (*Rattus exulans*), Brown Rats (*R. norvegicus*) and the House Mouse (*Mus musculus*). Two islands larger than 10 km^2 have now been cleared of rats (Atkinson 2001). Saunders and Brown (2001) recently concluded that the eradication of rats from Lord Howe Island is now technically feasible and this initiative is currently under consideration by the Lord Howe Island Board. The prospects for reestablishing *D. australis* once rats have been eradicated have yet to be fully explored, but initial indications appear favourable.

Possibility of populations on other islets

The discovery of a population of *D. australis* on Balls Pyramid does not engender much hope of finding a population on Lord Howe Island. This conspicuous, large insect has not been seen on the Island since the 1920s, despite numerous searches. Its absence is not surprising given that there is nowhere on Lord Howe Island that is free of rats. However, now that it is known that *D. australis* is capable of occupying habitats very different to its former habitat on Lord Howe Island, there is a remote possibility that this species may occur on other islets within the Lord Howe Group that are free of rats. Searches conducted on Blackburn and Roach Islands (Figure 1) in February 2001 found no evidence of *D. australis*. Although *Melaleuca howeana* bushes were common, no potential daytime refugia, such as seeps or accumulations of damp organic material were present. As far as is known, other islets within the Lord Howe Group also lack this specific habitat. Nonetheless, these other islets should be searched. The removal of the red tips of *Melaleuca howeana* by grazing individuals was clearly evident on Balls Pyramid, and this feature, together with the presence of frass, provides a relatively rapid means of determining whether *D. australis* are present.

Significance of this discovery for other extinct species

D. australis was not the only species to disappear from Lord Howe Island soon after the introduction of rats; five species of endemic birds were also lost (Hindwood 1938). Although *D. australis* has now been rediscovered, there appears little likelihood of any of the extinct birds still surviving. These species were all very conspicuous and highly mobile, and had they survived, they are unlikely to have escaped detection for 70 or so years.

Generally, most insects exist as large populations (IUCN 1983). The discovery of *D. australis* on Balls Pyramid has demonstrated that a large invertebrate can persist at very low population numbers, in very localised microhabitats, for a very long period of time. Aside from its possible parthenogenetic mode of reproduction, there appears to be no particular characteristic of this species that can explain why it should have such a high resilience to extinction at low population density. Facultative parthenogenesis is common in insects, but also occurs in many other invertebrates and in some higher order taxa such as reptiles (Dubach et al. 1997). Parthenogenesis potentially enables a population to recover from extremely low levels, including just a single female individual.

Based on knowledge of the former habitat of *D. australis* on Lord Howe Island – damp tree hollows – it is almost inconceivable that the species could exist on Balls Pyramid, where there are no trees and very few moist areas. It is both remarkable and surprising that the species can survive in a habitat that is so different from that which it formally occupied. However, this is not the only instance of an extinct species being rediscovered in a habitat that is uncharacteristic or suboptimal. The Bermuda Petrel (*Pterodroma cahow*), for example, used to nest in soil burrows under the forest floor. Thought to be extinct for 300 years (Verrill 1902), this species was rediscovered in 1951 nesting in rock cavities on a few small offshore islands that were devoid of both vegetation and soil (Murphy and Mowbray 1951). Such discoveries give some hope, however slight, of finding other 'extinct' species alive in localised habitats. It is clear, however, that when attempting to locate these animals, searches should not be restricted to those habitats with which the species was formerly associated.

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References

Atkinson I.A.E. 2001. Introduced mammals and models for restoration. Biological Conservation 99: 81–96.

Dubach J., Sajewicz A. and Pawley R. 1997. Parthenogenesis in the Arafuran file snake (*Acrochordus arafurae*). Herpetological Natural History 5: 11–18.

Edgecombe J. 1987. Lord Howe Island: World Heritage Area. Australian Environmental Publications, Balmain, Australia.

Etheridge R. 1889. The general zoology of Lord Howe Island. Australian Museum Memoirs 2: 3–42.

Gurney A.B. 1947. Notes on some remarkable Australian walkingsticks, including a synopsis of the genus *Extatosoma* (Orthoptera: Phasmatidae). Annuals of the Entomological Society of America 40: 373–396.

Higgins P.J. and Davies S.J.J.F. 1996. Handbook of Australian, New Zealand and Antarctic Birds. Vol. 3: Snipes to Pigeons. Oxford University Press, Melbourne, Australia.

Hindwood K.A. 1938. The extinct birds of Lord Howe Island. Australian Museum Magazine 6: 319–324.

Holland J. 2001. On the brink. Macleay Museum News 17: 4.

Hutton I. 1991. Birds of Lord Howe Island: Past and Present. Ian Hutton, Coffs Harbour, Australia.

Hutton I. 1998. The Australian Geographic Book of Lord Howe Island. Australian Geographic, Terrey Hills, Australia.

IUCN 1983. The IUCN Invertebrate Red Data Book. IUCN, Gland, Switzerland.

IUCN 2000. 2000 IUCN Red List of Threatened Species. IUCN, Gland, Switzerland.

Key K.H.L. 1991. Phasmatodea. In: CSIRO Division of Entomology, The Insects of Australia. Melbourne University Press, Carlton, Australia, pp. 394–409.

Lea A.M. 1916. Notes on the Lord Howe Island phasma, and on an associated longicorn beetle. Transcripts, Proceedings of the Royal Society of South Australia 40: 145–147.

Mandis Roberts Consultants 1999. Lord Howe Island World Heritage Property strategic plan for management. Mandis Roberts Consultants, Surry Hills, Australia.

Mazzini M. and Scali V. 1980. Ultrastructure and amino acid analysis of the eggs of the stick insects, *Lonchodes pterodactylus* Gray and *Carausius morosus* Br. (Phasmatodea: Heteronemiidae). International Journal of Insect Morphology and Embryology 9: 369–382.

McAlpine D.K. 1966. Rediscovery of Lord Howe Island phasmid. Australian Entomological Society News Bulletin 2: 71.

Montrouzier X. 1855. Essai sur la faune del'ile de Woodlark ou Moiou. Annales De La Societé D'Agriculture De Lyon 7: 1–114.

Murphy R.C. and Mowbray L.W. 1951. New light on the cahow (*Pterodroma cahow*). Auk 68: 266–280.

Opler P.A. 1976. The parade of passing species: extinctions past and present. Science Teachings 43: 30–34.

Paramonov S.J. 1963. Lord Howe Island, a riddle of the Pacific, Part III. Pacific Science 17: 361–373.

Pickard J. 1983. Vegetation of Lord Howe Island. Cunninghamii 1: 133–265.

Saunders A. and Brown D. 2001. An assessment of the feasibility of eradicating rodents from the Lord Howe Island Group. Endangered Species Recovery Council, Hamilton, Australia.

Smithers C.N. 1970. On some remains of the Lord Howe Island Phasmid (*Dryococelus australis* (Montrouzier)) (Phasmida) from Ball's Pyramid. Entomologist's Monthly Magazine 105: 252.

Standard J.C. 1967. Islands and seamounts to the east of Australia. Australian Natural History 15: 382–387.

Towns R.T., Daugherty C.H. and Cree A. 2001. Raising the prospects for a forgotten fauna: a review of 10 years of conservation effort for New Zealand reptiles. Biological Conservation 99: 3–16.

Veitch C.R. and Bell B.D. 1990. Eradication of introduced mammals from the islands of New Zealand. In: Towns D.R., Daugherty C.H. and Atkinson I.A.E. (eds), Ecological Restoration of New Zealand Islands. Department of Conservation, Wellington, New Zealand, pp. 137–146.

Verrill A.E. 1902. The 'Cahow' of the Bermudas, an extinct bird. Annals of the Magazine of Natural History 7: 26–31.

Westwood J.O. 1859. Catalogue of Orthopterous Insects in the Collection of the British Museum. Part 1, Phasmidae. Gurney and Jackson, London.

Wilkinson B.A. and Willson R.K. 1981. The Main Line Fleet of Burns Philip. The Nautical Association of Australia, Canberra, Australia.